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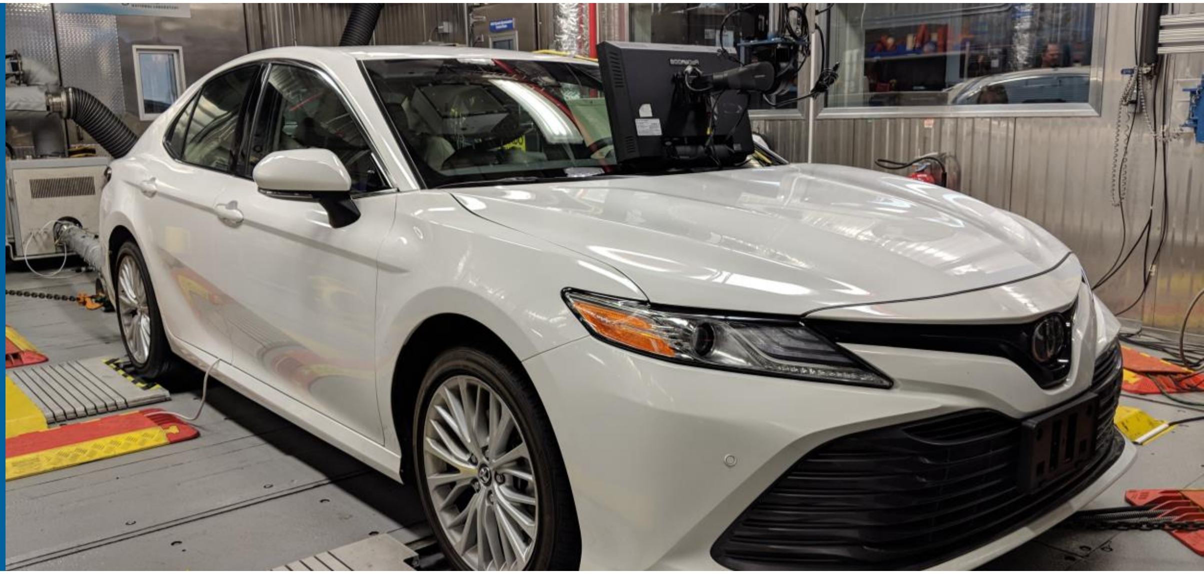
Argonne NATIONAL LABORATORY

ANL CORE TOOLS - HARDWARE

PROJECT ID# EEMS041



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2020 Vehicle Technology Office Annual Merit Review
June 2, 2020

OVERVIEW

Timeline:

- Project Start Date – 10/1/2018
  - Task 1- Vehicle in the Loop (VIL)
  - Task 2- Aero
- Project End Date- 9/30/2021
- Percent Complete- 50%

EEMS Barriers Addressed:

1) Rapid evolution of vehicle technologies and services enabled by connectivity and automation
2) Accurately measuring the transportation system-wide energy impacts of connected and automated vehicles
3) Difficulty in sourcing empirical real-world data applicable to new mobility technologies such as connectivity and automation

Budget:

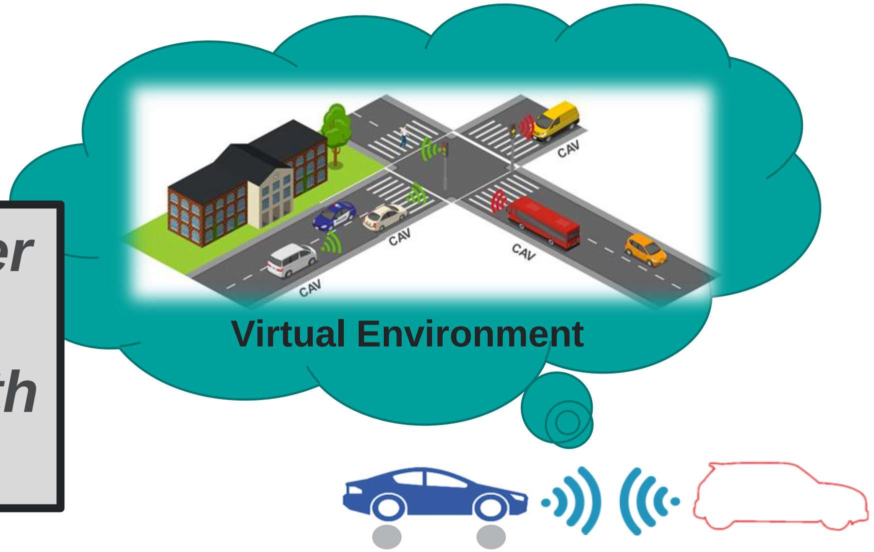
- FY20 Project Funding:
  - $500k: Vehicle in the Loop (VIL)
  - $250k: Aero
- FY21 Project Funding:
  - To Be Determined

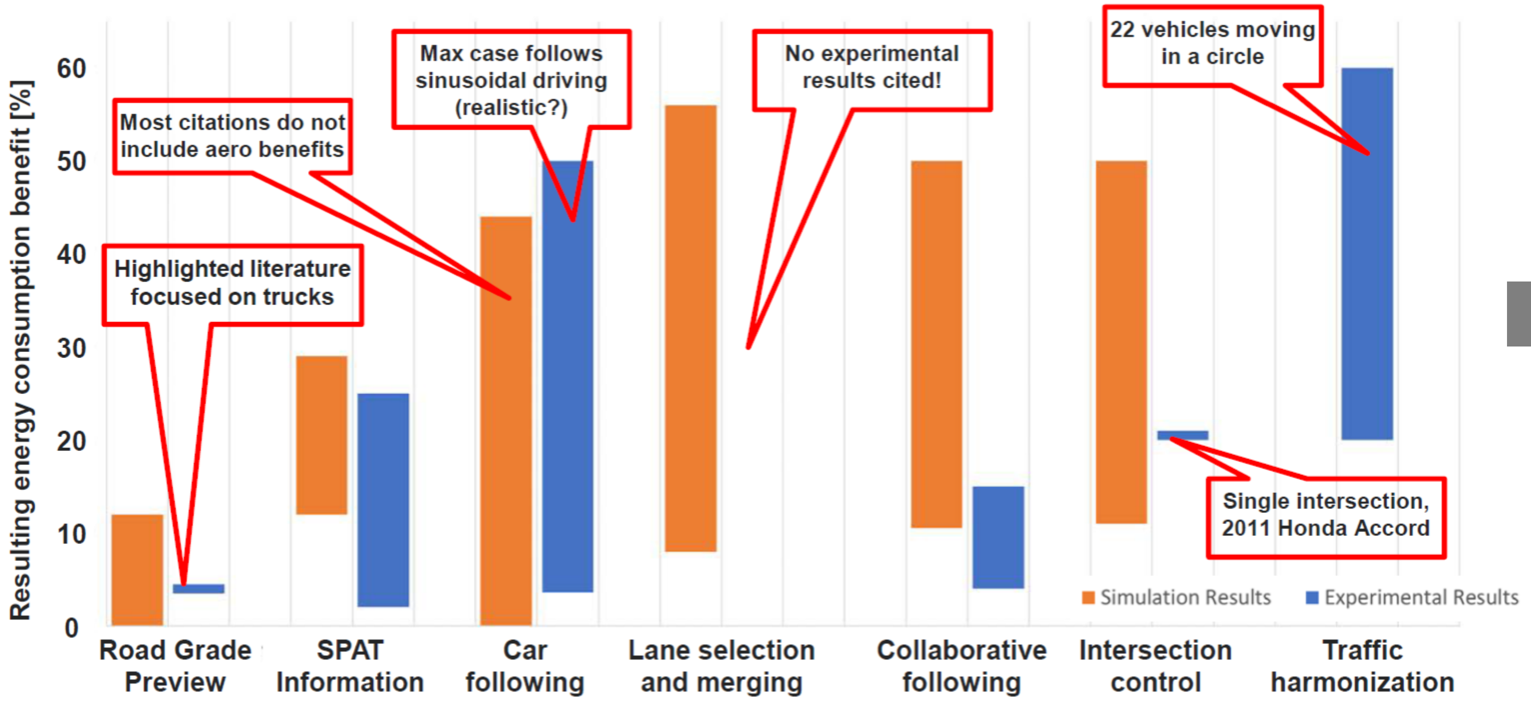
Collaborations / Partners:

- ANL / DOE Vehicle Modeling & Control PI's
- Ecocar Mobility Challenge
- DOE Smart consortium researchers
- ANL Cybersecurity Research
- DOT NHTSA

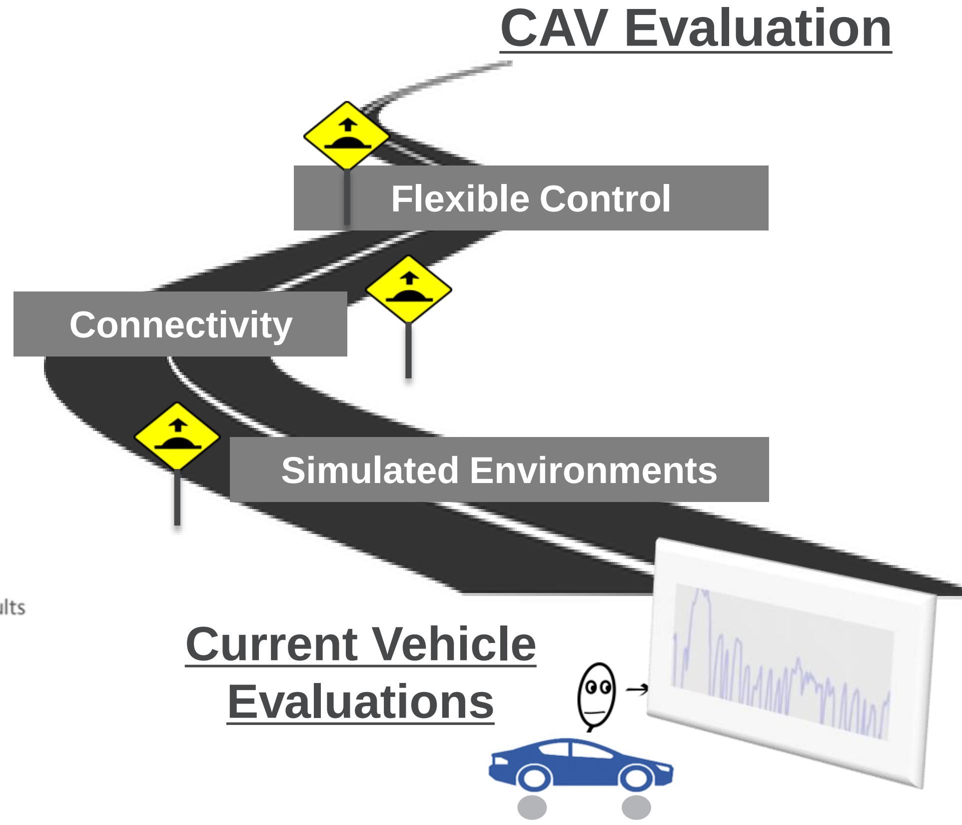
RELEVANCE

Connected and Automated Vehicle technologies offer a large, but variable impact to energy consumption. Quantifying the impacts requires unique tools in both <u>Simulation & Experimentation</u>

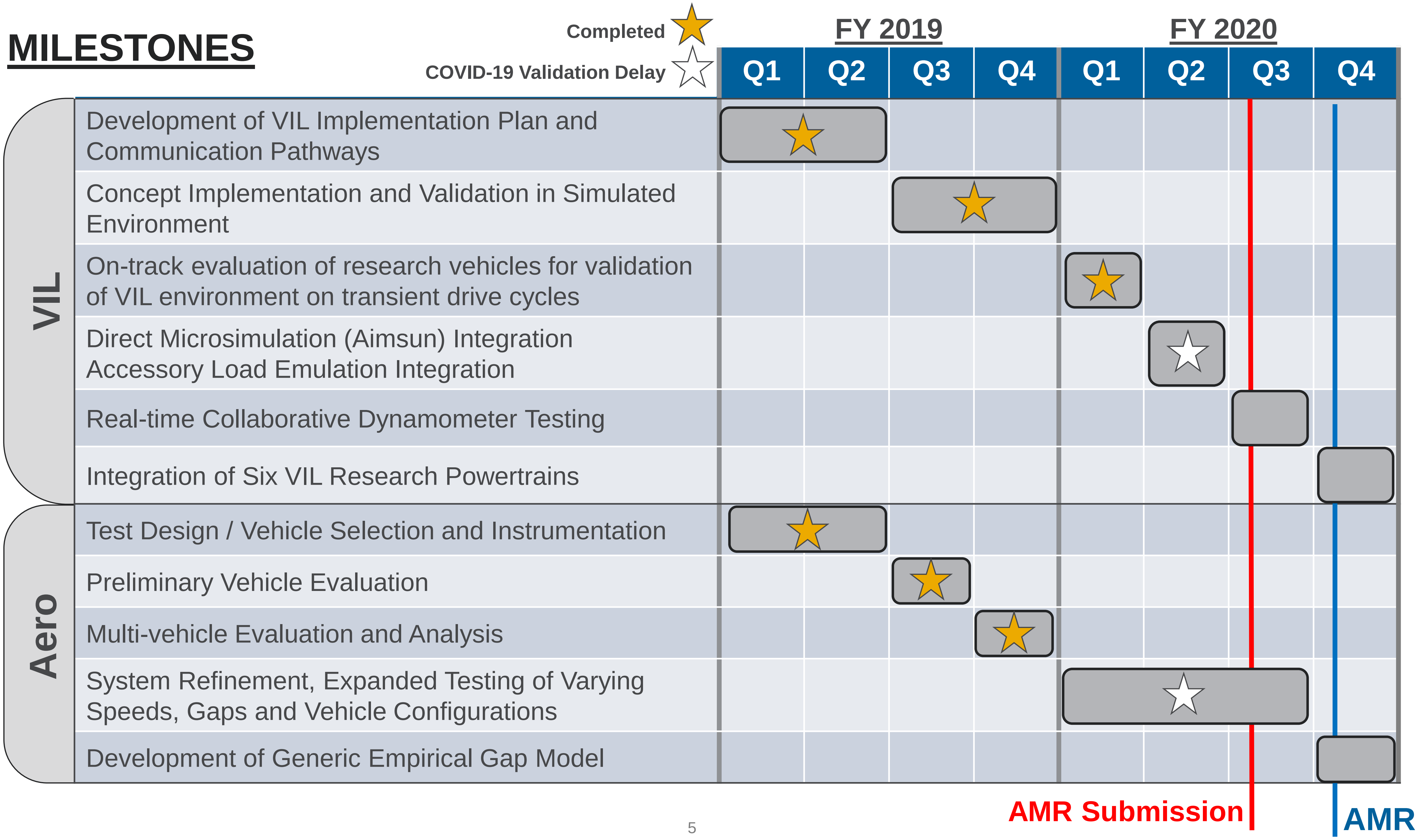




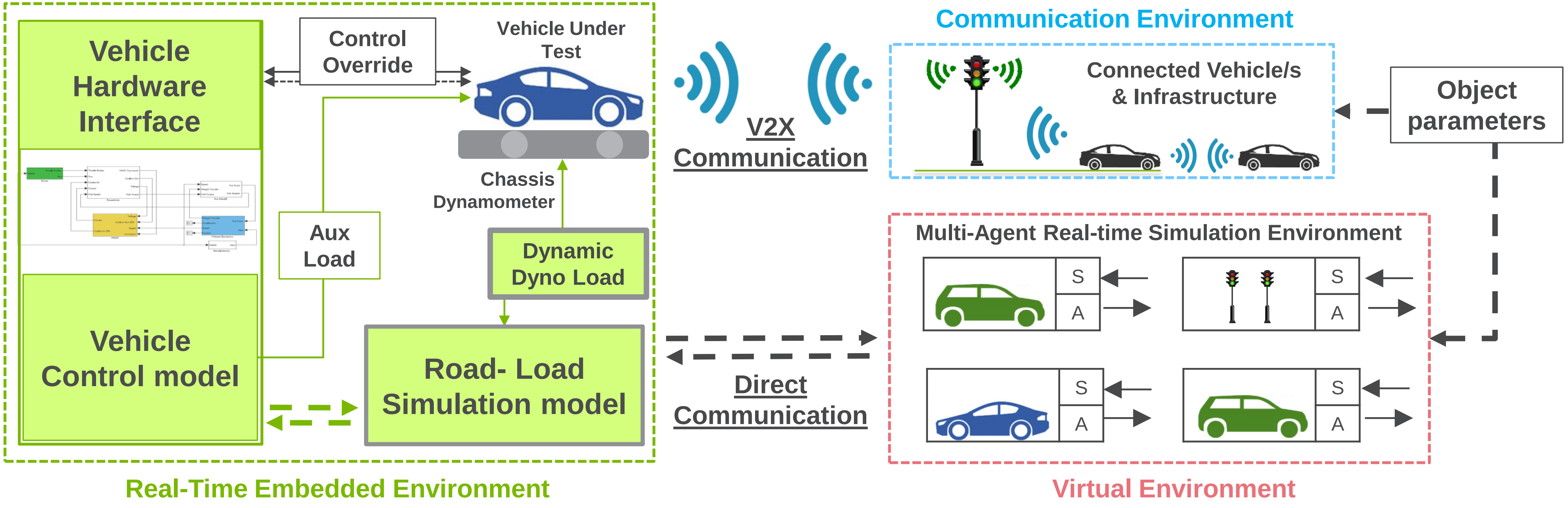
Source: Vahidi, Ardalan, and Antonio Sciarretta. "Energy saving potentials of connected and automated vehicles." Transportation Research Part C: Emerging Technologies (2018).



MILESTONES


Completed
COVID-19 Validation Delay
FY 2019
FY 2020
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
VIL
Development of VIL Implementation Plan and Communication Pathways
Concept Implementation and Validation in Simulated Environment
On-track evaluation of research vehicles for validation of VIL environment on transient drive cycles
Direct Microsimulation (Aimsun) Integration
Accessory Load Emulation Integration
Real-time Collaborative Dynamometer Testing
Integration of Six VIL Research Powertrains
Aero
Test Design / Vehicle Selection and Instrumentation
Preliminary Vehicle Evaluation
Multi-vehicle Evaluation and Analysis
System Refinement, Expanded Testing of Varying Speeds, Gaps and Vehicle Configurations
Development of Generic Empirical Gap Model
AMR Submission
AMR

APPROACH: VEHICLE IN THE LOOP (VIL) WITH DIRECT CONTROL OVERRIDE



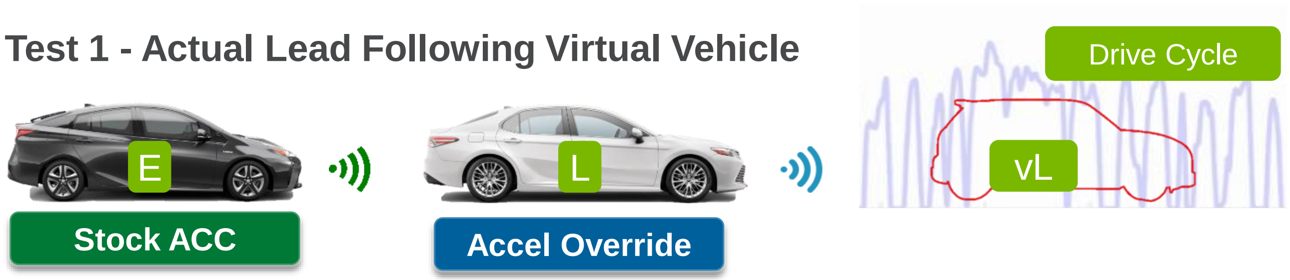
By providing a unique, vehicle system focused environment for intelligent/connected vehicle systems, Vehicle-in-the-Loop (VIL) offers the following benefits:

- Flexible- Variable powertrain (EV, Conv, …) / development - safe testing environment
- Precise and Repeatable- Controlled variation of specific test parameters
- Safe- Vehicle testing is in a stationary, controlled environment
- Reduced cost- Continuous testing (non human-driven) not requiring offsite travel
- Portable- Following validation, hardware and control may travel with vehicle (track testing?)

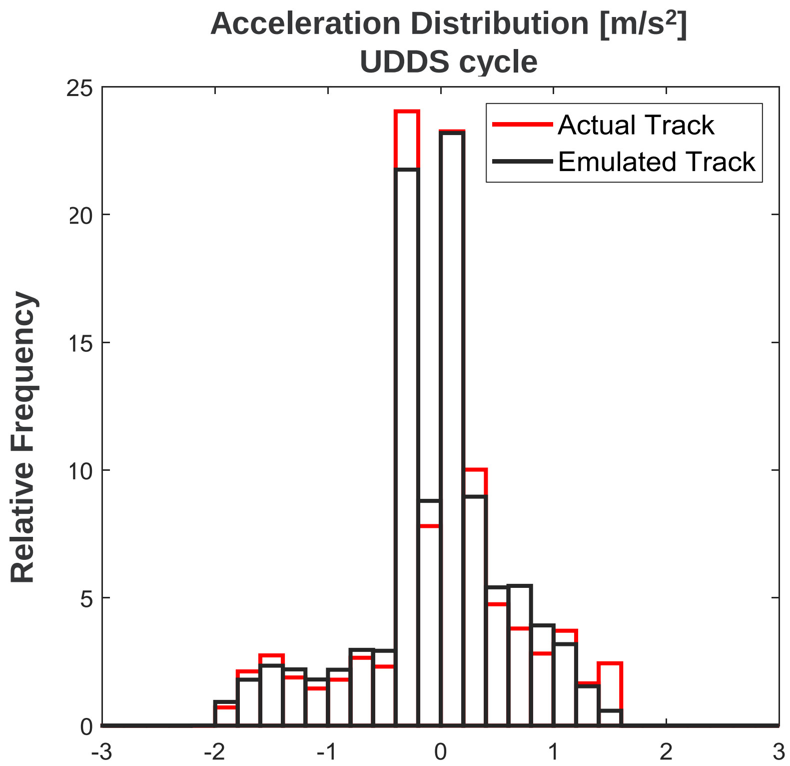
ACCOMPLISHMENTS: VIL ON-TRACK EVALUATION

Goal : ***Validate VIL override operation and vehicle response characteristics on a safe, controlled test track***

Test 1 - Actual Lead Following Virtual Vehicle



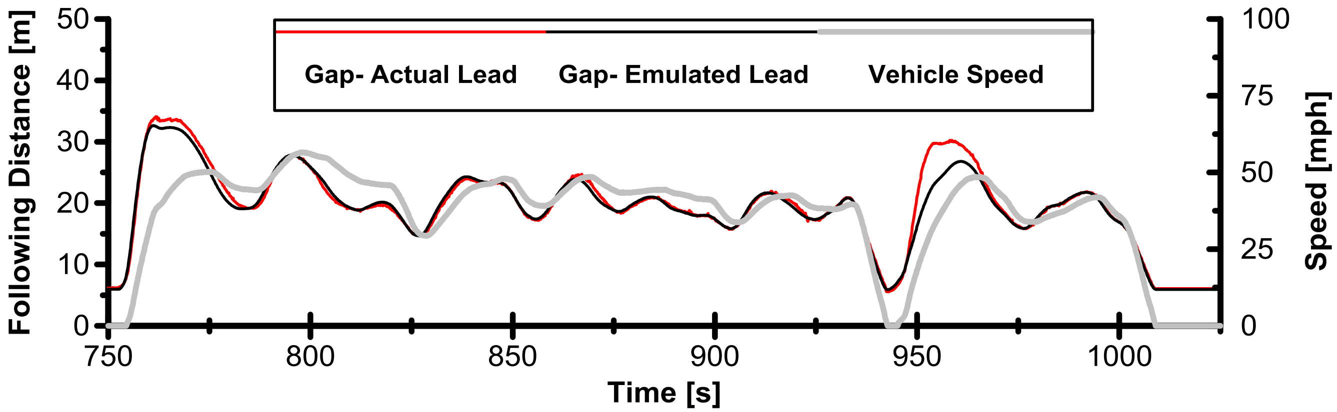
Test 2 – Virtual Lead Driving Recorded Actual Trace



Result: Override is effective & repeatable for longitudinal VIL control- variability from external factors (weather, animals, & driver variability) demonstrates concept benefits

Track testing methodology

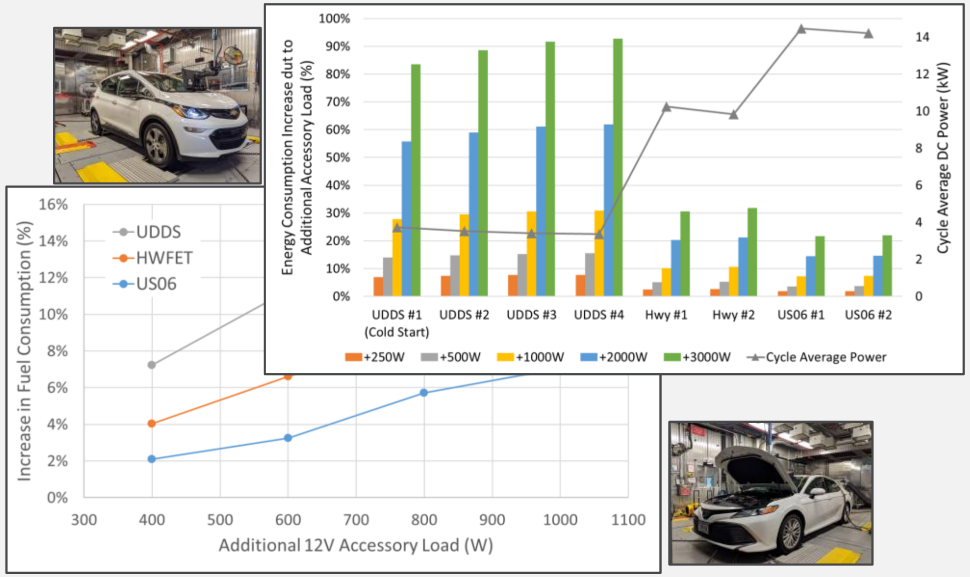
- Operate test vehicle with actual & emulated lead to verify consistent operation
- Evaluate on certification and custom cycles
- Compare ECU commanded acceleration and following gap from vehicle communication



ACCOMPLISHMENTS: DYNAMIC ACCESSORY LOAD EMULATION

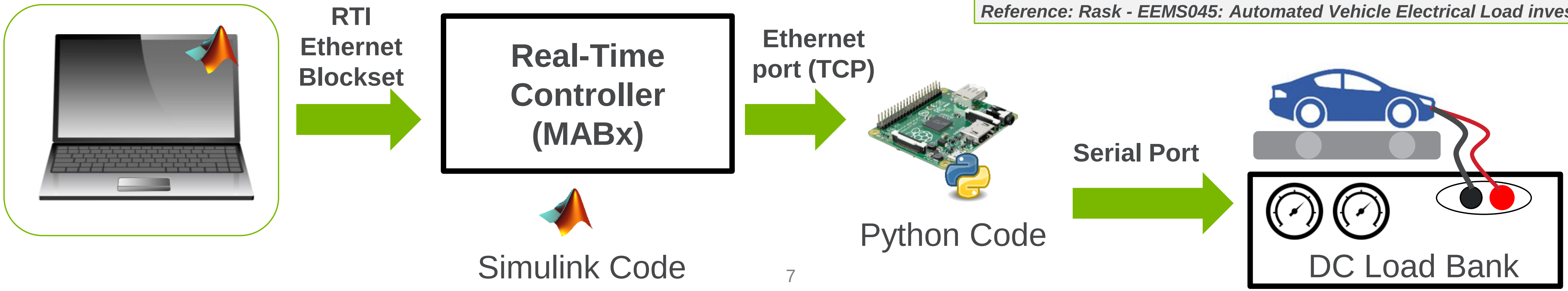
Goal : ***Integrate methodology for dynamic application of low-voltage loads such as those from driver assistance systems or power steering***

- **Load simulation interface**: Implemented models for dynamic loading within dyno experimentation
- **Communication interface**: Established communication between real time controller and DC load bank- dynamically requesting loading to the vehicle low voltage system
- **Dynamic loading**: Dynamic loading needed for VIL - static loading demonstrated in EEMS045



Vehicle Accessory Loading During Dyno Testing

Reference: Rask - EEMS045: Automated Vehicle Electrical Load investigation



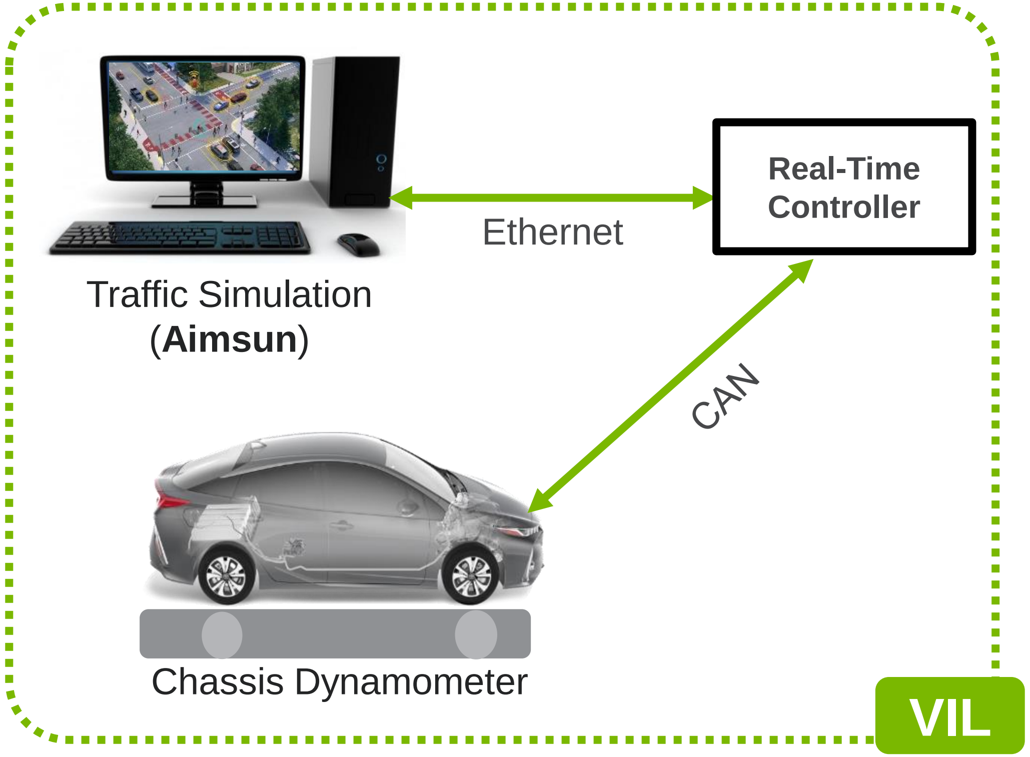
ACCOMPLISHMENTS: VIL AIMSUN INTEGRATION

Goal : ***Connect a traffic simulation platform with vehicle on-board ECUs to experimentally assess the energy impacts of CAVs technologies on a traffic network level***

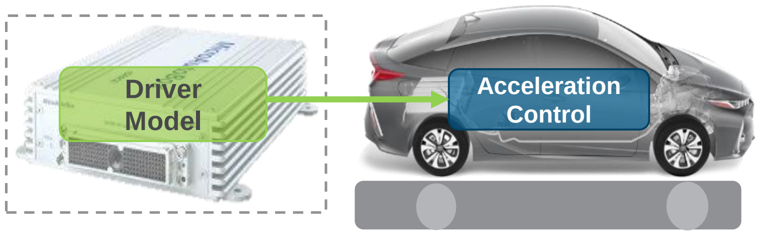
Why is it needed (Motivation) :
- Many ADAS functions interact with other traffic participants. These entities need to be included in the simulation to evaluate the energy / safety impact associated with the interactions.
- As the vehicles become more complex and include more communication systems, their performance should be evaluated on a larger geographical scale and larger number of connected vehicles s integration of different software tools on different operating systems.

Advantages :
- Reduced testing time and resources used (efficient)
- Simulations can be repeated in an accident free environment (safe)
- CAV technologies can be tested in advanced traffic simulations modeled with experimentally collected data (to create representative test scenarios - reliable)
- Stimuli data can be modified in real time to evaluate the effect on the ADAS functionalities
- Modularized components/models and common IOs can be used : the system is flexible and the workflow can be expanded to include new stages (or existing stages that need validation)

Challenges :
- Co-simulation (traffic, vehicle, powertrain) requires integration of different software tools on different operating systems

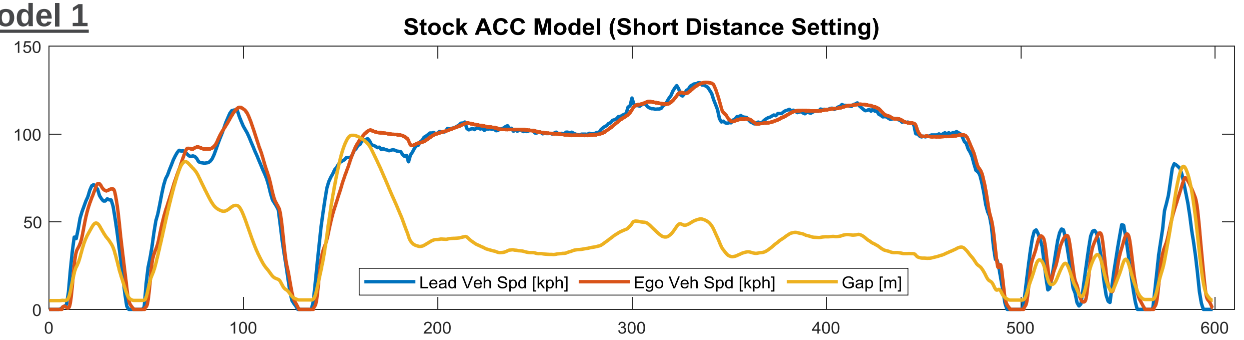


<u>ACCOMPLISHMENTS</u>: DRIVER MODEL VARIABILITY

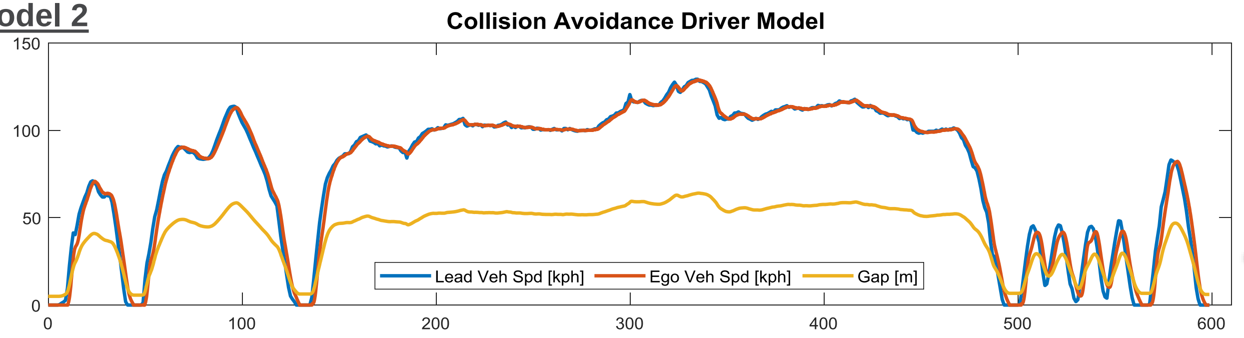


Goal : ***Explore the energy use impacts of varying <u>driver models</u>***

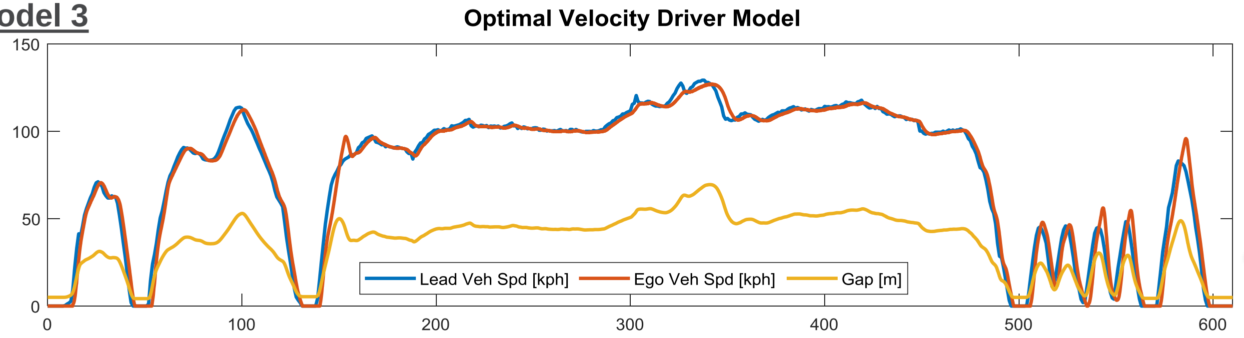
<u>**Driver Model 1**</u>



<u>**Driver Model 2**</u>



<u>**Driver Model 3**</u>



Result: Effective & repeatable method for energy use quantification of varying vehicle control

Driver Model	Fuel Economy [mpg]*
Trace Following	**49.0**
Stock ACC	50.9 (+3.9%)
Collision Avoidance	51.8 (+5.7%)
Optimal Velocity	53.2 (+8.6%)

* SOC Corrected

<u>**References**</u>

- <u>Model 2</u>: Collision Avoidance Model

MathWorks, "Adaptive Cruise Control with Sensor Fusion", available online : *https://www.mathworks.com/help/driving/examples/adaptive-cruise-control-with-sensor-fusion.html*

- <u>Model 3</u>: Optimal Velocity Model

Islam, M., R., "Comparison of Vehicle Dynamics of Microscopic Car Following Models : Optimal Velocity and Intelligent Driver Model", 2014

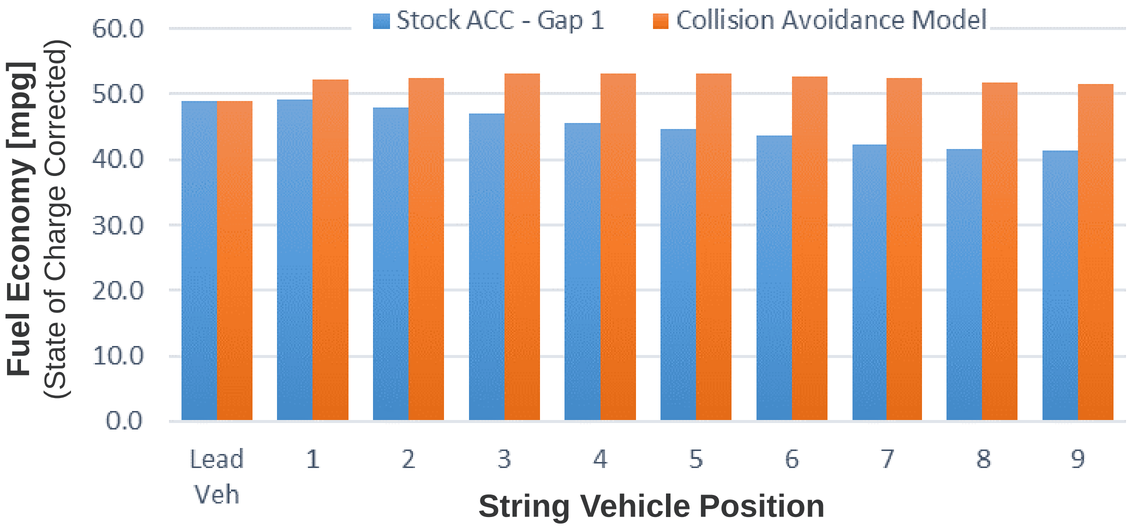
ACCOMPLISHMENTS: VEHICLE POSITIONING VARIABILITY

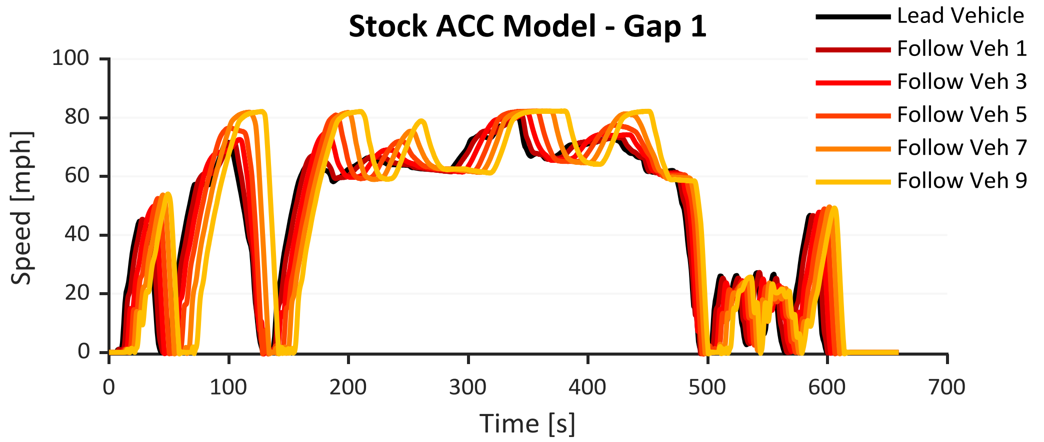
2017 Toyota Prius Prime

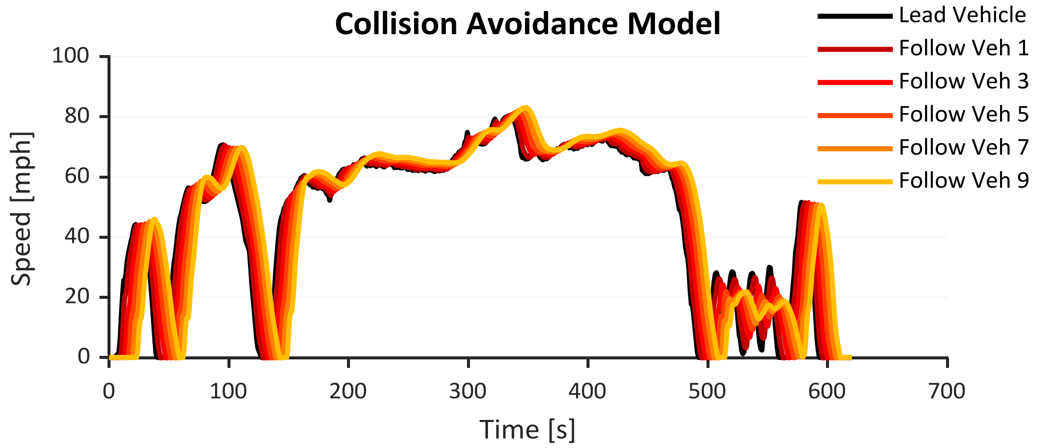
Vehicle in HEV mode

Goal : ***Explore the energy use impacts of vehicle position in a string of ten ACC vehicles with two different driver models.***

- Consistent test vehicle & drive model
- Virtual lead vehicle operates on aggressive US06
- Test vehicle follows speed profile of test vehicle immediately prior

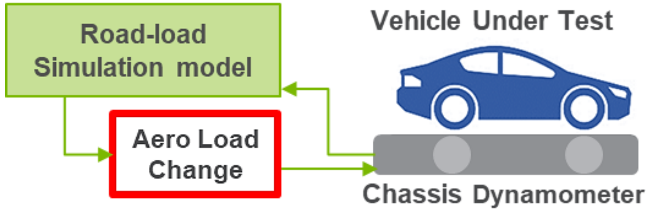






Result: Energy use impacts of a driver model affect not only the current vehicle, but also surrounding traffic.

APPROACH: AERODYNAMIC LOAD CHANGES WITH AUTONOMOUS DRIVING



Road load force from axle torque

Autonomous Vehicle Driving Choices:
- Stay close: **lower drag**, higher traffic density
- Keep distance: smoother driving controls, efficiency

Limitations in Current Literature:
- CFD simulations
- Wind tunnels
- Actual road testing data is out-of-date and sparse

Project Vision:
- **Provide modelers empirical aerodynamic load changes with a set of equations:**
  - **Inputs: Speed, Gaps, Vehicle profiles**
  - **Output: Change in aerodynamic road load for each vehicle**

Phase One: Proof of concept
- Measured tractive force changes in two cars.
- Lessons learned used in phase 2

Phase Two: Multi-Car with Controls
- Measured tractive force changes as function of gap for **three cars in platoon**.
- Literature CACC **gap controls** adapted for controller
- **Lead & rear vehicle** controlled w/pedal signal
- Larger track gave **better data**

Phase Three: (future) Design of Experiments
- Multi-vehicle, multi-gap
- DoE testing with CFD support for generalized equations

ACCOMPLISHMENTS: COMPUTER-CONTROLLED THREE-VEHICLE ROAD LOAD MEASUREMENTS ON-TRACK

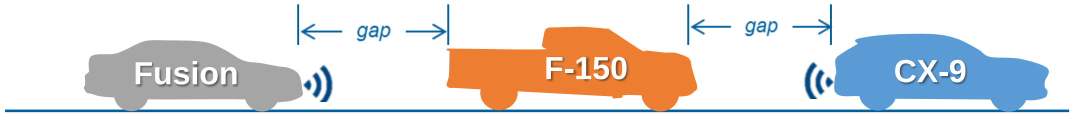
Pre-experiment Development

Step 1:
Identify appropriate CACC control equations

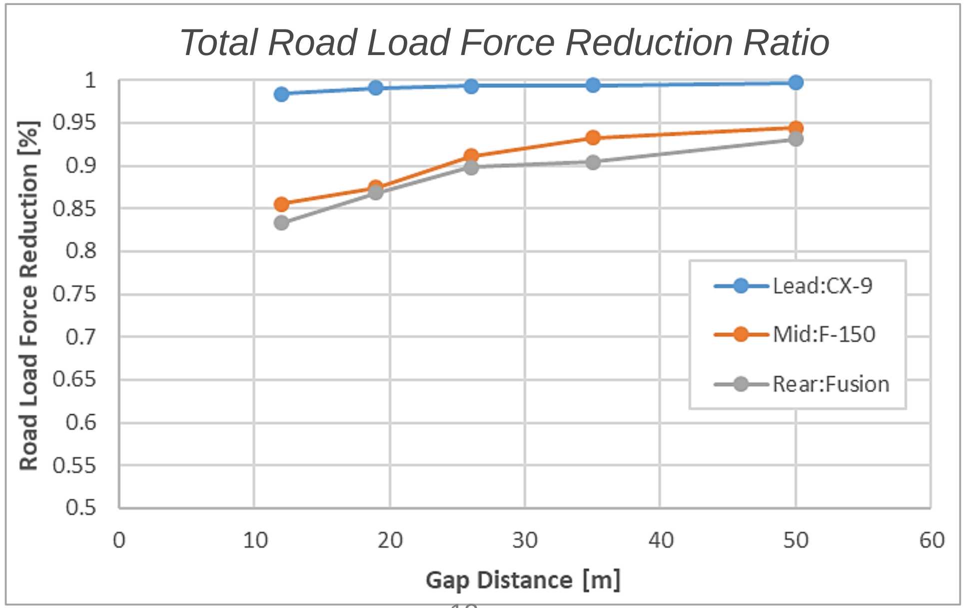
Step 2:
Modify equations to set both gap and speed

Step 3:
Tune parameters in simulation (stability, response)

Step 4:
Tune on track.



- Three-vehicle setup / vehicle control method validated
- Prior simulation tuning saved considerable track time tuning
- Much better data at larger track
- Optical LIDAR gap sensor still problematic (switching to radar)
- Monotonic road load reductions (robust results)
- Lead vehicle showed small but measureable reduction
- Middle vehicle (F-150) showed similar results as rear (Fusion)



Longer, 7.5-mile track

<u>RESPONSES TO REVIEWER COMMENTS</u>: FY2019

- *This work is very well designed. The reviewer suggested the research project moves further; however, it would be helpful to fine-tune the approach tailored towards certain end-users. Currently, it is **<u>not clear what specific use cases this project can address</u>**. Although, that is understandable because the project is still in its early stages.*

<u>Response</u>: This effort has been to develop core capabilities in the testing and evaluation of CAV impacts. Specific research efforts focusing on a specific use case will be funded separately to ensure progress on concept development.

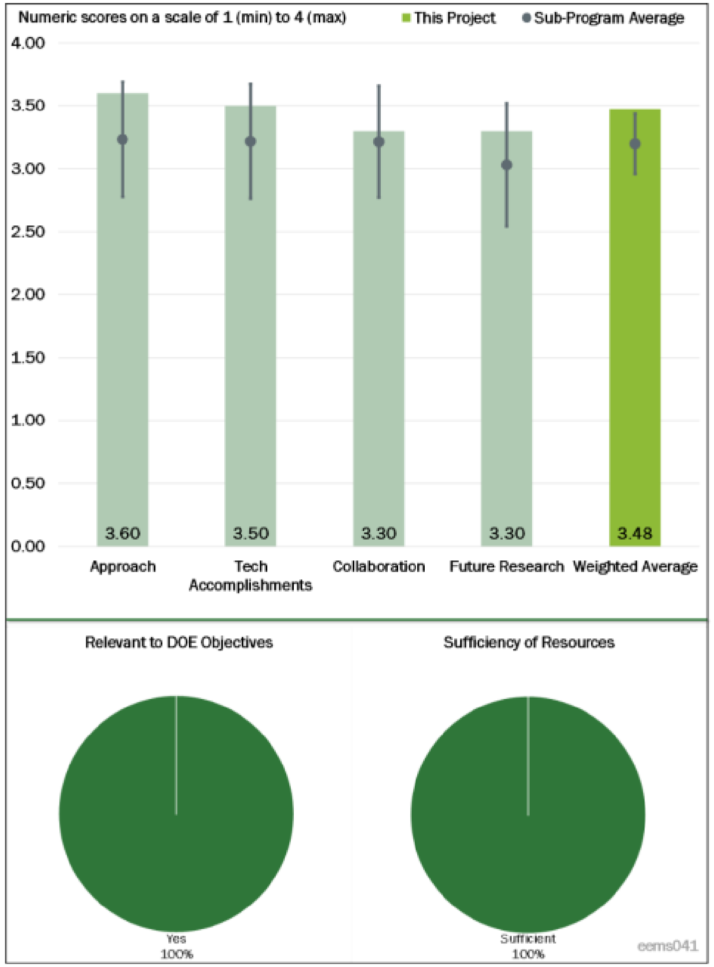
- *A **<u>model of aerodynamics based on test data is expected</u>** based on the track test results and **<u>a deeper analysis of fuel/energy consumption differences for hybrid-EV and EV is expected</u>**.*

<u>Response</u>: A model of aerodynamics based on test data was developed in FY19, and later integrated for use in the VIL environment. HEV/EV energy consumption differences are being explored as new powertrains and functionalities are enabled.

- *The proposed research work is planned in a logical manner. The reviewer suggested the **migration of risks in vehicle override in different vehicles and vehicle platooning track test should be planned**.*

<u>Response</u>: Safe, accurate testing is a critical portion of this project. A thorough safety plan has been developed and reviewed by all levels of ANL management for on-road and on-track testing, and is being implemented

<u>FY2019 Project Review Results</u>



COORDINATION: EXISTING COLLABORATIONS WITH OTHER INSTITUTIONS

DOE National Laboratory Partners:

- **Ecocar Mobility Challenge (Development of Ecocar Chevrolet Blazer)**
- ANL Modeling and Simulation (ANL RoadRunner Integration)
- DOE SMART Research Efforts
- ANL Cybersecurity Research

Outside Partners / Collaborators:

- US DOT- NHTSA
  - Test vehicles and equipment support
- Universities
  - Wayne State University (Graduate Student Support)
  - Clemson University (Data / CAN support)
  - Michigan Tech (Data / CAN support)
- Publicly available vehicle data
  - www.anl.gov/d3

REMAINING CHALLENGES AND BARRIERS FOR THIS PROJECT

Vehicle-In-the-Loop

- Development of unique testing methods for implemented research platforms

  No standard method for energy use evaluation of CAV technologies

- Implementing additional vehicles requires implementing “hooks” unique to each vehicle. These hooks are non-standard, and are often a research project in themselves.
- Ensuring speed and reliability of communication across multiple laboratories and between Microsimulation and Real-Time environment.
- Consistent Realistic representation of vehicle loading requires real-world testing, data collection, and analysis for quantification and model development

Aero

- Numerous staff required, DAQ system is being automated for more efficient data capture
- Inexpensive gap sensor not as reliable as radar, using radar for next track testing runs
- Coupling CFD with track testing to develop generic empirical road load reduction model

PROPOSED FUTURE WORK FOR THIS PROJECT

Vehicle-In-the-Loop

- Extension of vehicle-centric Vehicle-in-the-Loop testing environment
  - Collaborative dynamometer test facilities
  - Expansion of vehicle connectivity into simulated environment
  - Driver-in-the-Loop
- Expansion of research vehicle fleet to enable additional research powertrains
  - Variation in both manufacturer and powertrain architecture (conv / HEV / EV)
  - Expansion of vehicle control overrides (SOC, gear,…)

Aero

- Expanded test set varying speeds, gaps and surrounding vehicle configuration
- Work with an OEM doing CFD modeling to augment testing, reduce test cases, fill gaps
- Develop a generic, empirical model used by modelers to account for surrounding vehicle gaps

Note- Any proposed future work is subject to change based on funding levels

SUMMARY

Relevance

- Innovative methods of experimentation are required to accurately quantify the impact of future automotive technologies on Mobility, Energy, and Productivity.

Approach

- Development of a vehicle-centric testing environment for model validation and direct research into Connected and Automated Vehicle (CAV) technologies.
- Quantification of road-load impact of vehicle platooning through direct measurement.

Highlighted Accomplishments

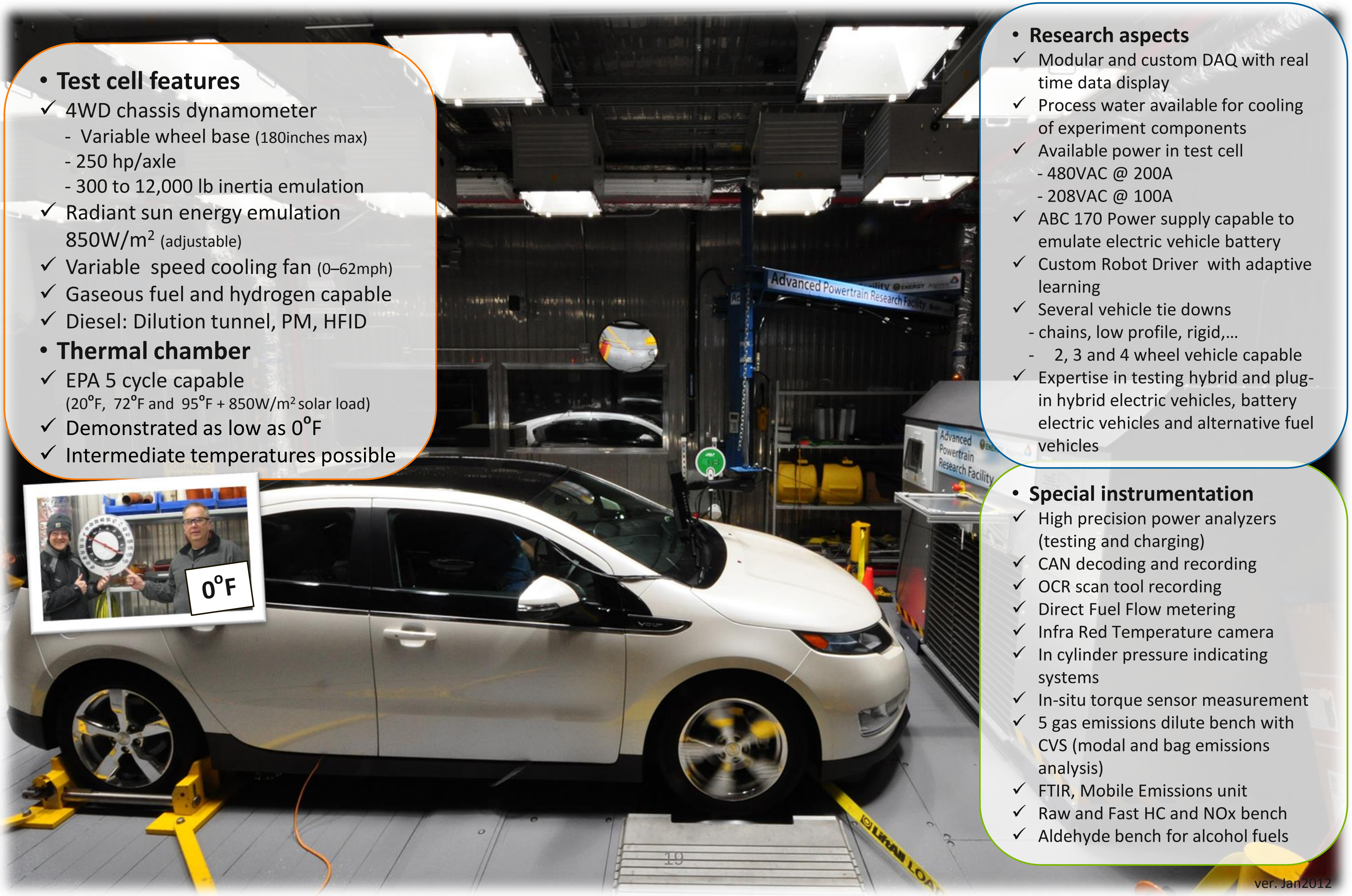
- VIL- Continued development of core capabilities and validation of methodology through comparative dyno to track testing
- VIL- Exploration analysis of energy use impacts of driver models and vehicle positioning
- Aero – Execution of multi-vehicle aero study

TECHNICAL BACK-UP SLIDES

ADVANCE MOBILITY TECHNOLOGY LABORATORY
4WD CHASSIS DYNAMOMETER THERMAL TEST CELL

Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY



- **Test cell features**
  - ✓ 4WD chassis dynamometer
    - Variable wheel base (180inches max)
    - 250 hp/axle
    - 300 to 12,000 lb inertia emulation
  - ✓ Radiant sun energy emulation 850W/m^2 (adjustable)
  - ✓ Variable speed cooling fan (0–62mph)
  - ✓ Gaseous fuel and hydrogen capable
  - ✓ Diesel: Dilution tunnel, PM, HFID
- **Thermal chamber**
  - ✓ EPA 5 cycle capable (20°F, 72°F and 95°F + 850W/m^2 solar load)
  - ✓ Demonstrated as low as 0°F
  - ✓ Intermediate temperatures possible

- **Research aspects**
  - ✓ Modular and custom DAQ with real time data display
  - ✓ Process water available for cooling of experiment components
  - ✓ Available power in test cell
    - 480VAC @ 200A
    - 208VAC @ 100A
  - ✓ ABC 170 Power supply capable to emulate electric vehicle battery
  - ✓ Custom Robot Driver with adaptive learning
  - ✓ Several vehicle tie downs
    - chains, low profile, rigid,…
    - 2, 3 and 4 wheel vehicle capable
  - ✓ Expertise in testing hybrid and plug-in hybrid electric vehicles, battery electric vehicles and alternative fuel vehicles

- **Special instrumentation**
  - ✓ High precision power analyzers (testing and charging)
  - ✓ CAN decoding and recording
  - ✓ OCR scan tool recording
  - ✓ Direct Fuel Flow metering
  - ✓ Infra Red Temperature camera
  - ✓ In cylinder pressure indicating systems
  - ✓ In-situ torque sensor measurement
  - ✓ 5 gas emissions dilute bench with CVS (modal and bag emissions analysis)
  - ✓ FTIR, Mobile Emissions unit
  - ✓ Raw and Fast HC and NOx bench
  - ✓ Aldehyde bench for alcohol fuels

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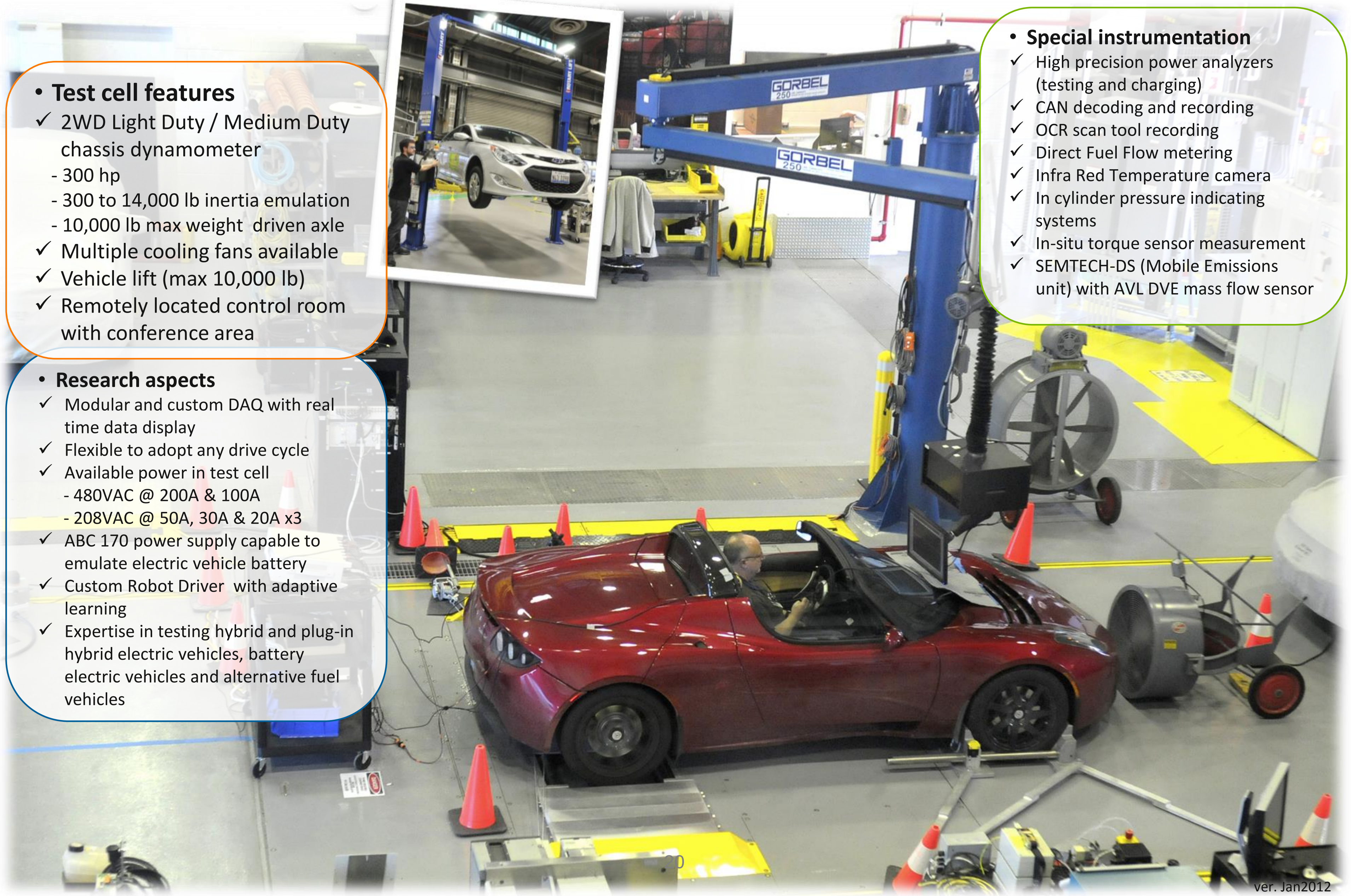
ADVANCED MOBILITY TECHNOLOGY LABORATORY
2WD CHASSIS DYNAMOMETER



- **Test cell features**
  - ✓ 2WD Light Duty / Medium Duty chassis dynamometer
    - 300 hp
    - 300 to 14,000 lb inertia emulation
    - 10,000 lb max weight driven axle
  - ✓ Multiple cooling fans available
  - ✓ Vehicle lift (max 10,000 lb)
  - ✓ Remotely located control room with conference area

- **Research aspects**
  - ✓ Modular and custom DAQ with real time data display
  - ✓ Flexible to adopt any drive cycle
  - ✓ Available power in test cell
    - 480VAC @ 200A & 100A
    - 208VAC @ 50A, 30A & 20A x3
  - ✓ ABC 170 power supply capable to emulate electric vehicle battery
  - ✓ Custom Robot Driver with adaptive learning
  - ✓ Expertise in testing hybrid and plug-in hybrid electric vehicles, battery electric vehicles and alternative fuel vehicles

- **Special instrumentation**
  - ✓ High precision power analyzers (testing and charging)
  - ✓ CAN decoding and recording
  - ✓ OCR scan tool recording
  - ✓ Direct Fuel Flow metering
  - ✓ Infra Red Temperature camera
  - ✓ In cylinder pressure indicating systems
  - ✓ In-situ torque sensor measurement
  - ✓ SEMTECH-DS (Mobile Emissions unit) with AVL DVE mass flow sensor